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ALUMINIUM DIE CASTINGS.

Paper presented to the Coventry Section, 6th March, 1929, by J. G. Heritier.

ALLOW me, first of all, to define the scope of this lecture. The term "Die Casting" is used in England to connote the casting of molten metal in metal moulds, with or without the mechanical application of pressure, so that two distinct types of castings—the aluminium gravity die casting and the aluminium pressure die casting—are thereby designated under this term. It is the author's intention only to refer in this short lecture to the most important of these two types of castings, i.e., the aluminium gravity die castings.

General Properties of Aluminium Gravity Die Castings.

The physical properties of a casting are largely dependent upon the crystal size and, in general, metal with a coarse crystalline structure is less strong and less ductile than one with a close-grained formation of the crystals. The size of the crystals depends very largely upon the rate of cooling; and the slower the mass of metal is allowed to solidify the larger the crystals will grow. Therefore, other things being equal, the casting made from a metal mould will normally be stronger than one cast in sand owing to the much greater rate of heat conduction through the metal mould. For instance, a 4 per cent. Binary aluminium copper alloy will give,

sand cast, 7½ tons tensile with 4.9 tons yield with 5 per cent. elongation. The same alloy chill cast will give 9.6 tons per square inch with 5.4 tons yield and 10 per cent. elongation. This means, therefore, that all aluminium gravity die castings should possess comparably increased strength over aluminium sand castings of the same design and made in the same alloys; and designers who know the physical properties of the light aluminium alloys rightly expect (when changing over from aluminium sand castings on to aluminium gravity die castings) to be able to cut down casting sections in proportion without reducing the safety factor of the castings. I wish to point out, however, that the greater strength shown by the die cast test bars will be found in the die castings themselves only if these are thoroughly sound, that is to say, free from hot short cracks and crystalline porosity. This is an important point which designers must not lose sight of, for costly failures have already been caused through faulty aluminium die castings.

It is regrettable to see what little attention manufacturers give to aluminium castings generally. Sufficient care is taken to see that the various alloy steels used in the manufacture of an engine, for instance, are constantly checked for analysis and physical properties but, in regard to aluminium castings, so long as no obvious cracks, visible to the naked eye, have been found during rough inspection, it is generally taken for granted the castings are sound and reliable. No attempt is made to check the strength of the castings and to see whether the alloy supplied is capable of withstanding the stresses the castings will be subjected to. It is difficult to understand such gross neglect when it is remembered that aluminium castings are often very heavily stressed; and it is the firm opinion of the author that if manufacturers would only take the obviously necessary care to ensure the aluminium castings they are being supplied with are made in the correct specified alloy, and free from physical defects, many aluminium gravity die castings, or castings sold as such on the English market to-day, would never be put through the first machining operation.

This remark does not imply that aluminium gravity die castings are unsafe, for aluminium gravity die castings of very large size and complicated design can be made and are consistently being made to a degree of physical soundness which satisfies the most exacting laboratories. You may ask, therefore, why are not all aluminium gravity die castings physically sound.—Because the solidification shrinkage to which all types of castings are subjected plays a considerably more important part in the ultimate soundness of aluminium gravity die castings than it does in aluminium sand castings for instance. That is to say, the casting difficulties due to solidification shrinkage are considerably more difficult to overcome in gravity die castings owing to the fact that castings are

formed in incompressible metal dies, and further, because for obvious reasons it is not possible to place feeders at any point of the castings.

The total amount of shrinkage in castings is made up of three different parts :—

(1) The volume contraction in the liquid metal as it cools from pouring temperature to the solidifying point.

(2) The contraction which takes place on changing from the liquid to the solid condition. This is called the crystallisation shrinkage.

(3) The solid contraction (similar to the liquid contraction) which occurs in the casting from the solidifying point to the normal temperature.

The first and third contractions depend on temperature fall and do not vary greatly with the alloy composition, since all aluminium alloys have about the same co-efficient of expansion and do not differ widely in melting point.

To minimise as much as possible the liquid contraction, it is advisable to cast at a temperature as low as casting thickness will allow. The solid contraction, however, is not affected by pouring temperature and depends entirely on temperature of solidification and thermal coefficient, both of which are outside control. To avoid the trouble known as hot short cracks which this contraction may cause, it is essential to design the dies so that the castings can be released without strain from the dies soon after they have solidified.

The second contraction, or crystallisation shrinkage, is in a quite different category from the other two thermal shrinkages. It is independent of the temperature fall, but depends largely upon the alloy composition. In this respect different alloys behave very differently. The low shrinkage of the aluminium silicon alloys, for instance, has been ascribed to the fact that while aluminium itself contracts on solidifying (as do most metals) silicon is an exception and expands.

The crystallisation shrinkage takes place over the small range of temperature between the point where solidification begins and that at which it is complete. This varies with alloy composition and while pure aluminium and certain alloys (like the 12 per cent. Silicon Aluminium alloy, for instance) solidify instantaneously, the majority of aluminium castings pass through a pasty stage where they are neither liquid nor solid. The effect of crystallisation shrinkage takes the form of shrinkage holes and porous cracks, either at the surface or, more commonly, within the face of the metal where they are not apparent until the casting is machined or until it breaks under stress in service.

It is not possible to prevent crystallisation shrinkage from occurring, but in correctly designed dies it is arranged that the

shrinkage will take place at points where it will do no harm, that is to say, in the feeders, which are cut off from the casting afterwards. On this depends, to a large extent the ultimate soundness of the casting, and unless the dies, which later on will be used for production, are carefully designed so that the crystallisation shrinkage is counteracted, or rather driven out of the casting itself, the castings produced will be unsound and, therefore, unfit to withstand stresses in service.

How to design dies so that the die castings produced will be sound in every part and free from the physical defect which the solidification shrinkage will tend to cause, even in the simplest of castings, is not an easy task. No general laws can be laid down, each die requiring careful and independent study. It may be remarked, however, that the way in which castings are poured is a matter of the utmost importance and when designing a die the placing of the pouring point, or points, requires most careful consideration. Any mistake in this direction is fatal. Close uniformity of grain throughout the various sections of the castings is the ideal result to be obtained. This result depends entirely on uniformity of solidification and—while designing a die it is generally advisable to be liberal as regards the number and size of feeders, for economy of metal in this respect will often lead to extravagance in scrapped or unsound castings.

Most Important Commercial Gravity Die Casting Alloys.

The strength of the casting depends not only on its freedom from foundry defects, but also on the physical properties of the alloy in which it is made. It is therefore imperative that castings which will be subjected to stresses in service are made in an alloy having physical characteristics suitable for the work the castings will have to perform. Unfortunately, this vital point is often overlooked and motor manufacturers are generally too willing to accept castings made in alloys unsuitable for the duties which will be required from them. As an instance, it is known to the author that die cast motor cycle crankcases made in an aluminium copper alloy containing 12-13 per cent. copper are being fitted to some motor cycle engines. This alloy is much too brittle and, therefore, unsafe for this type of casting. The manufacturers should only use aluminium castings made in the approved alloys and should, furthermore, specify the alloy they require for each type of casting and insist that the castings they are supplied with are correctly made to specification.

The most important light aluminium alloys suitable for stressed parts are :—

The Binary alloys of aluminium and copper containing from 6 to 8 per cent. copper and known under the Airboard specification No. 2L.11.

The Ternary alloy of aluminium, zinc and copper, containing from 12.5 to 14.5 per cent. zinc, 2½-3 per cent. copper and known under the Air Board specification No. L.5.

The 2L.11 aluminium copper alloy is extensively used in all countries. It has a specific gravity (die cast) of 2.87 to 2.93 and its average physical properties are, at normal temperature, in the chill cast state, 10 to 11 tons per square inch with a yield point of seven tons and an elongation of 3-4 per cent. The physical properties of this alloy (like all the Binary aluminium copper alloys containing over 2 per cent. copper) can be considerably improved by suitable heat treatment. It must be pointed out, however, that the copper content of this alloy must not exceed 8 per cent., as additional copper reduces considerably the ductility of the alloy.

The second alloy referred to, and known as L.5 has, at normal temperature, physical properties considerably better than 2L.11. At 15° Centigrade it has an ultimate stress of 11-14 tons per square inch with a yield point of about six tons and an elongation of 4-10 per cent. Unfortunately, the strength of this alloy falls very rapidly with rising temperature and its ultimate strength falls from round fourteen tons to as low as four tons per square inch at 250° C., and is only about 1½ tons per square inch at 350° C. Consequently this alloy suffers greatly from hot shortness, and is therefore difficult to die cast satisfactorily. For this reason the 3L.11 aluminium copper alloy is in many cases preferable to L.5 for die-castings, as unless the design of the casting is fairly simple the L.5 die casting will contain numerous hot short cracks (not necessarily visible to the eye) which will affect the strength of the casting considerably. In any case, castings likely to be subjected to elevated temperatures must never be made in this alloy.

For castings which are not subjected to any great stresses, the silicon aluminium alloys may be used satisfactorily. Also in their normal state these alloys present no advantage (from the user's point of view, at any rate) as compared with 2L.11 or L.5 alloys.

An alloy of 5 per cent. silicon and 95 per cent. aluminium, for instance, gives eight tons per square inch ultimate, with 5 per cent. elongation, results inferior to a 5 per cent. copper aluminium alloy. Increase in the percentage of silicon give very little improvement in strength and reduces the ductility considerably.

The above remarks only refer to the aluminium silicon alloys in their normal state, as the modified process (which improves considerably the physical properties of the aluminium-silicon alloys) cannot be satisfactorily applied when producing die castings in bulk quantities. The silicon aluminium alloys are not easily machinable and their elastic limit is so low that castings made in this alloy may be permanently stretched by loads well below the ultimate value. For this reason, heavily stressed castings should not be made in these alloys. Manufacturers should note this, for

the silicon aluminium alloys are the favourite alloys of die casters owing to their remarkable freedom from troubles in the foundry. These alloys do not suffer from hot shortness owing to the fact that their shrinkage on solidification is low and their strength and elongation are comparatively high at solidification temperature. Consequently it is considerably easier to make apparently sound die castings in these alloys and most die casters will willingly supply aluminium silicon castings in preference to 3L.11 or L.5 castings if the casting user will allow them to do so.

In order to try to raise the low elastic limit and also improve the machining properties of the silicon aluminium alloys, the ternary aluminium alloys of aluminium, silicon and copper have been developed. Alloys containing round 3 per cent. silicon and 4 per cent. copper are being used in the States. These are claimed to give in the die cast state, eight to nine tons tensile with 2-3 per cent. elongation, the elastic limit occurring at a high proportion of the breaking load. This ternary aluminium copper silicon alloy possesses little ductility, however, and can only be recommended where castings of high yield point are specially required.

Light Aluminium Alloys for Piston Castings.

The large majority of pistons for internal combustion engines are now made from aluminium alloy die castings, this being due mostly to the high thermal conductivity of aluminium, which enables aluminium alloy pistons to work at a temperature below the flash point of lubricating oils, thereby permitting the use of higher compression ratio which makes for greater engine efficiency.

Quite a number of light aluminium alloys have been specially developed for piston work and entirely unfounded claims have been made for some of them.

In England the aluminium alloys most commonly used for piston work are the Binary alloys of aluminium and copper, containing from 8-12 per cent. copper. These alloys retain a fair proportion of their strength up to a temperature of 300° C. In the neighbourhood of 200 to 250° C. all the aluminium copper alloys containing from 6-14 per cent. copper have practically the same tensile strength (7 tons per square inch), but at somewhat higher temperatures and up to 350° C., the alloys containing from 12-14 per cent. copper are better than those containing lower proportions. For this reason the alloy containing 12 per cent. copper, and generally known by its Air Board specification No. L.8 is most extensively used for piston work.

The thermal conductivity of the 8-12 per cent. copper aluminium alloys (expressed in terms of gramme calories conducted per square centimetre per second across a slab 1 cm. thick having a temperature difference of 1° C. per centimetre) is .39 at 100° C. and. 41 at 250° C.

An aluminium alloy containing 14 per cent. copper, 1 per cent. manganese, remainder aluminium was developed for piston work during the War; manganese having the property of stiffening materials at high temperature and aluminium copper alloys containing 1 per cent. manganese show an actual increase in strength up to 250° C. The 14 per cent. copper, 1 per cent. manganese alloy has a tensile of ten tons per square inch at 250° C. as compared with seven tons for the plain 12 per cent. copper aluminium alloy. This promising alloy was discounted, however, as the advantage of manganese renders the alloy very brittle and also reduces slightly the thermal conductivity.

Further tests were made on aluminium copper alloys containing small addition of high melting point metals such as iron, molybdenem, tungsten, chromium, vanadium, etc., as it had been thought the presence of an intermetallic compound having a very high melting point a considerable degree of hardness might render the alloy stiff and hard at elevated temperatures. None of these alloys showed any advantage over the 14 per cent. copper 1 per cent. manganese alloy and it was found that the comparatively small addition of the third element renders the material extremely brittle and unsatisfactory from a casting point of view, as this high melting intermetallic compound crystals out during solidification in a honeycomb-like structure within which the main portion of the crystallisation shrinkage occurs, resulting in an unsound, porous casting.

Special reference must be made to a remarkable aluminium alloy which has been developed by the National Physical Laboratory and which is highly satisfactory for piston work in particular. This alloy, known as " Y " metal, contains 4 per cent. copper, 2 per cent. nickel, 1½ per cent. magnesium, remainder aluminium. Its tensile strength, which is round fourteen tons per square inch (in the chill cast un-heat-treated condition) at normal temperature does not fall so rapidly with rising temperatures as for the binary alloys of aluminium and copper, and at 250° C. the tensile strength of this alloy is still about ten tons per square inch. These remarkable results (which can be further improved by suitable heat treatment) together with the fact that the thermal conductivity of the alloy is equal to that of the aluminium copper alloys, make " Y " metal the most satisfactory piston alloy at present.

The advantages of piston alloys having been pointed out, mention must also be made of their disadvantages. The disadvantages of aluminium alloy pistons are :—

(1) Their higher coefficient of thermal expansion as compared with cast iron.

(2) The more rapid wear and abrasion of the surfaces also the greater liability of sticking of the piston rings.

Wear and scoring of the surfaces and also sticking of the piston

rings (which results from pinning of the metal between the ring grooves by impact with the cylinder walls) are largely a matter of alloy. If aluminium alloys approaching the rigidity and hardness of cast iron can be made and used, it is probable that the rate of wear and the danger of scoring and pinning of the piston rings will be comparable with the latter. Developments are being made in this direction.

Dimensional Accuracy of Aluminium Gravity Die Castings.

Ridiculous claims have been made at times regarding the dimensional limits within which aluminium gravity die castings can be produced in bulk. Aluminium gravity die castings are not and cannot be produced within the same close dimensional limits obtainable in pressure die castings for the obvious reason that gravity die casting dies have to work at a considerably higher temperature than is the case for pressure, casting dies and die distortion, which sets up under heat, affects to a more or less considerable extent the dimensions of the casting produced.

It is one of the problems of the die designer to design dies so that this unavoidable distortion will affect the casting dimensions to the least possible extent. Fairly close accuracy is nevertheless obtainable in aluminium gravity die castings and machining operations in the castings can often be cut out, the casting being consistently produced within the limits specified on the casting drawing.

Correctly designed and accurately machined dies can produce castings within the following tolerances :—

(1) Circular holes and slots can be produced with a dimensional accuracy of plus or minus $\frac{1.5}{1{,}000}$ of the dimension, but a minimum cone or taper of a $\frac{1}{4}°$ a side is necessary.

(2) Centre dimensions and important overall dimensions not controlled by the die joints can be produced within a dimensional accuracy of plus or minus $\frac{2}{1{,}000}$ of the dimension.

(3) Dimensions controlled by the die joints require wider limits. The accuracy to which they can be cast depends on the complication and size of the dies.

It is not practicable to cast holes of less than one-eighth-inch in diameter, especially if these are placed near the runner of the casting. Internal threads cannot be cast in satisfactorily and it is only practicable to die cast external threads if these are coarse and of fairly large pitch.

Summary.

Although the various industries (motor industry in particular) are using more aluminium die castings every day, the strides made

in this direction are not as rapid as they should be. Taking the motor industry, for instance, the necessity for a high-power weight ratio is fully recognised. The avoidance of unnecessary weight makes for reduced fuel consumption, better acceleration and improved breaking power.

Cutting down on weight in one part of the machine by substitution of an aluminium alloy for a heavier one, not only reduces the weight of that part alone, but requires less heavy frame, springs, etc., to carry the total weight. Thus, savings of weight are cumulative, rather than additive.

An aluminium casting of suitable design can always be replaced by an aluminium die casting which will possess the same strength with considerably less weight, and if designers will only go to the trouble of designing their various aluminium castings so as to make them satisfactory die casting propositions (and this is possible in almost every case), they could improve the performance of their car and reduce its cost at the same time.

The author hopes these last remarks will arouse the interest of designers sufficiently and result in a better and more rapid utilisation of the advantages afforded by aluminium gravity die castings.

THE TRAINING OF YOUNG ENGINEERS.

Paper presented to the Institution, Coventry Section, 11th March, 1929, by D. R. MacLachlan, B.Sc., A.M.I.C.E., Principal, Coventry Technical College.

THE great majority of young people who enter the engineering industry are elementary school pupils who leave the school at fourteen years of age, and only about 25 per cent. of these attend continuation classes for further education. This unsatisfactory state of affairs is due to a variety of causes, the chief of which are : (*a*) lack of parental control or indifference of parents to the further education of their children ; (*b*) desire on the part of the boys to enjoy the newly-acquired freedom from school discipline.

The importance of continuing their education is impressed on the boys before leaving school, but if this is not supported by home influences it has little effect. I think we are correct in saying that these boys who attend classes do so with the idea of improving their prospects in life and they look forward to occupying positions of some responsibility greater than an ordinary craftsman, and the classes designed to help them in this ambition are the classes which are most popular. In a pamphlet recently published by the Board of Education on " Education for Industry and Commerce," Lord Eustace Percy, the President of the Board of Education, in the preface, writes : " The tradition of our evening schools from the early Mechanics' Institute to the modern Polytechnic has, in fact, been to meet the working-man's spontaneous demand for further education of all sorts, and particularly for the kind of education which will enable him to rise to positions of responsibility rather than to offer him training in the particular work in which he is employed at the moment. This is why, as is sometimes pointed out, a good deal of the money we spend on so-called ' technical ' education has no apparent effect in producing craftsmen or skilled workers, in other words, it has little to do with ' technique ' in the ordinary sense, and this will continue to be the case so long, at least, as attendance at ' technical ' courses is purely voluntary."

He says the courses " have no apparent effect in producing craftsmen." Now I submit that it is not the function of the Technical College to produce craftsmen, for craftsmen can only be produced in the factory, but what Technical Colleges do claim is that they raise the intelligence of the craftsmen who attend the classes.

The criticism is often put forward that the courses are not practical enough, and four years ago we inaugurated courses in Work-

shop Practice which included Workshop Practice, Drawing and Lectures in Workshop Methods and Calculations. The numbers enrolled for these courses have been most disappointing. The fact of the matter is there are many youths who look forward to spending their days as ordinary craftsmen, and are not prepared to sacrifice their leisure to make themselves more efficient, but are content to rely on the experience they can get in the factory, and this will continue to be the case so long as attendance at technical courses is purely voluntary. Hence it is that the courses are designed to meet the needs of those 25 per cent. willing to make sacrifices to improve their position.

The boys after leaving the elementary school at fourteen years of age attend for two sessions at one of the affiliated evening schools, and receive a preliminary training to prepare them for the higher courses at the Technical College. During these two years they receive instruction in Drawing, English, Mathematics, Elementary Science, and at sixteen years of age pass into the Technical College. The course followed by the student in Mechanical Engineering is shown on the leaflet for Part-time Courses, and for the evening students there is a similar course, but more restricted, as the part time day student has four hours for every three of the evening student. A five years course is arranged which gives the student guidance up to the age of twenty-one. It will be observed that during the first three years the subjects are Engineering Drawing, Practical Mathematics, and Engineering Science, and if a student satisfactorily completes this course the Institution of Mechanical Engineers in conjunction with the Board of Education grant an Ordinary Grade National Certificate in Mechanical Engineering. One great advantage of this scheme is that all examination papers are set by the teachers themselves, but the final examination papers are approved and the worked papers are assessed by assessors appointed by the Board of Education and Institution of Mechanical Engineers. Another advantage is that the courses may be varied to suit local needs provided the standard of education is not reduced and the syllabuses are approved by the Institution. A further two years course is arranged, and when successfully completed the Higher Grade National Certificate is granted under similar arrangements to those for the Ordinary Grade Certificate.

Since 1922 when the examinations were first instituted, 150 Coventry students have gained the Ordinary Certificate, and I find that they are now employed as follows :—

In drawing offices	74
In sales departments	5
As Technical Assistants and Assistant Managers ...	14
As Craftsmen	13
As Apprentices	14
As Clerks	4

The criticism has been made that the courses as at present framed are more suited for those intending to become draughtsmen, and these figures appear to justify the criticism; but I would suggest that positions in drawing offices are more likely to be given to youths who have shown ability in their studies than to those who have shown no aptitude or inclination for study. I am satisfied that the standard of education required for the Ordinary Certificate can be reasonably required of all who aspire to a position of responsibility in the works. I am not satisfied, however, that our fourth and fifth years could not be supplemented by another course of two years duration which would be more suitable for those engaged in actual production rather than design.

There is always a marked drop in the numbers attending the fourth year course compared with those in the third year. This is due to a variety of causes, among which may be mentioned: as a youth becomes older more demands on his time and energy are made in the works; he may feel he has reached the limit of his mathematical ability; he may be quite satisfied with his Ordinary Certificate; the subjects of the fourth and fifth year may not appeal to him.

The following table giving the numbers of students attending the various courses in Mechanical Engineering show the falling-off between the third and fourth years.

Nos. of Students Attending Classes in Mechanical Engineering.

Year of Course.	Evening Classes.	Day Classes.	Totals.
1	73	97	170
2	37	76	113
3	31	63	94
4	23	23	46
5	3	13	16

Some of those students who discontinue their studies after the third year might be induced to continue if offered a course dealing more directly with workshop processes, and I would offer the following suggestion for your consideration. Let your Institution arrange with the Board of Education for the issue of a National Certificate in Production Engineering to young men holding the Ordinary Grade National Certificate in Mechanical Engineering, and who have taken a further course of studies in workshop processes, economics and workshop organisation and management, and have passed the examinations which may be prescribed by your Council. Your Institution, with the expert knowledge of the requirements of the Production Engineer would specify what subjects would be accepted, and could then arrange to accept the certificate as an educational qualification for admission to your Institution as Graduate or Associate. Such a certificate would be very attractive to the young engineers, it would encourage them to

study workshop methods and practice, and by attaching themselves to an Institution such as yours would keep them in touch with modern development. I put forward this suggestion for your consideration in the hope that it will not only help the young engineer, but also help your Institution.

It is claimed for these courses of instruction that they develop the reasoning powers and intelligence, teach the fundamental principles underlying general engineering practice, enable students to read and make drawings, and to make all necessary calculations in production work.

Above all, it teaches the youth how to learn, and will enable him, when he comes to specialise in a particular branch, to study technical literature with better understanding and profit than if he had no such education.

This is the great value of education : it enables us to extend our knowledge. We know that nearly all our education has been acquired after we have left school, but our development largely depends on our preliminary training. These courses are designed to give each youth the best possible chance of development.

In conclusion, I would like to say a few words on the practical training. I do not think it desirable or possible to turn out skilled craftsmen from the Technical College Workshops. All we can hope to do is to give instruction which will enlarge the experience gained in the factory.

There are some firms in Coventry where youths who wish to get an all-round knowledge of their craft are given every possible assistance to do so, but there are others where the futures of the young people receive little or no consideration. I should be extremely interested to hear your views on the following questions :—

Is it possible to revive the apprenticeship system ?

Why is it that some firms can take apprentices and give them a good training, while others say they cannot do it ?

Is it that some employers realise their responsibility to their young employees, and are willing to assist them to become good craftsmen provided they show aptitude and diligence in their service ?

How is it that some employers give many of their young people the advantage of time off during working hours to attend classes, while others will not do so ?

Discussion.

Sir Alfred Herbert, who presided, said that they had had a very interesting paper. One of the great difficulties in educating engineers was to educate the educators, for none of those who were educating engineers could possibly decide exactly what was the best system of education to give them. It was impossible, because

there was such an immense variety of possible future occupations. An engineer was born and not made, but he was all the better for all the education he could get. If he was not born with the essential qualities then most of the education he got would never make him an engineer. If he were asked what an engineer was, he would find it extremely difficult to give a definition. The engineering profession, or trade, had innumerable branches, and each of the occupations again had innumerable classes of workers. You had got, broadly, designing, which was the foundation, production and the commercial side. So many engineers who had been geniuses failed by any commercial standard, though he did not think that a man failed because he did not make money. There was the case of the British-American engineer, the maker of the " Buick " car, who finished in absolute penury.

When a boy says, " I am going to be an engineer," he had not the remotest notion what kind of an engineer his own abilities and opportunities would lead him into. The problem of directing the education of the young engineer was a most difficult one, and if he were asked whether boys intended for engineering should be sent to a university, he confessed that he did not know the answer to give. All he could say was that there were many men who had turned out extraordinarily well after a university course. The young man at the university had advantages. He came into close contact with a circle of companions, he got the corners rubbed off and if he took an engineer's course he got a good deal of engineering theory and practice. It had taken three years of the most valuable part of his life to do it, and he came back again after his university career into the shops, but he did not come back quite so well situated for learning what the shop had to teach him as the boy who has gone through at sixteen or eighteen. Most of the engineering he himself had managed to pick up was picked up from his friends in the works during his apprenticeship, and he looked upon that part of the engineer's experience as being very practical. If it afterwards happened that he got a position of responsibility it was a very great asset to have that understanding and sympathy which could only be got by early association with the workers. Broadly speaking, the question was, were you to give education in a technical course with the idea that it should be a general education of a kind directed towards engineering, or were you to try to train a man to work machines ? He did not think you could train a man successfully to work machines in a technical school. You could give him a working knowledge, you could get him to understand how to carry out the ordinary A B C operations on the ordinary A B C machines. If you could teach a boy up to such an extent in a technical school to be a miller, or a driller, or a grinder, or a fitter, and when he went in to an up-to-date shop, he would be

taking his part with other people. That was not within the range of practical politics at all. Practice in the shops was changing continually. All workshop practice had to be carried on with the commercial idea at the back of it. When he was a young man, one of the tests was to file up a hexagon nut. What the technical school could do was to carry general education a stage further with a distinct mechanical aim. Draughtsmanship could be taught to a great extent, the use of figures as they applied to engineering, and so on, thus training the boys' minds—making them the more adaptable, the more ready to help themselves by learning—and it was possible that they might get some sort of practice in the workshops on simple processes, and the use of simple machines and simple work.

Mr. R. H. Hutchinson said that he was afraid that many of the employers did not appreciate how much the good of the engineering industry in Coventry was bound up with the question of the proper training of the young engineer. The question was asked as to whether it would be advisable to send one's son to a university. Since the universities had not yet thought fit to found a chair of production engineering, he would say that they had not yet appreciated what production engineering really meant, and therefore, it would be far better to leave them alone until they did realise it. Most of the training that a young man got in a town like Coventry, with part time and day time classes, could be of greater value to him than a university course. One of the great functions of the university was that it gave him the courage of his convictions. It was very much better to have a few convictions backed up by courage than a tremendous number of little-good convictions which were lacking in courage. A man might have big ideas in his mind but never get any further. Had the same young man had the advantage of a university education he might have risen to great heights.

They had heard that evening that you could not train a man to become a good craftsman. His education should be to teach him how to become a good craftsman. It was bound to rest on the man himself, and therefore, the technical education should teach him how to learn from what he saw going on around him all day long—how to apply his knowledge and how to use his brains in finding out what was meant by everything he saw. That, in his view, was the only way to train an engineer. The more one rose in one's profession the more one realised how much one was learning every day, and therefore, the line that one had got to pursue was what was the best kind of subject to train the young man's mind—to teach him how to apply the knowledge which he was getting from day to day in his work. It should be carefully impressed upon him that his knowledge did not consist only of the

things he learnt in the classes. What he learnt in his classes merely taught him to interpret what he saw in his work.

Mr. MacLachlan has asked some questions. It was a little difficult to know what exactly one meant to-day by the apprenticeship system. To-day the boy had an entirely different outlook on life and he did not think from the mentality of the young man to-day that it would be a good thing to revive the old-fashioned apprenticeship system. The only thing one could do was to find a boy to go through a certain course in the works. So long as he worked he had got to stay there and combine what he would learn in the works with the education which he could get in the classes. In any talk of an apprenticeship system one had got to take in the technical education side. You could not just teach young men to-day by the old-fashioned apprenticeship system. You had to combine with it technical education as well, so far as engineering is concerned. Some employers did realise their responsibility to the young engineers, and others did not. Any employer who had the welfare of his firm at heart could not neglect his apprentices. The success of any undertaking must depend on the efficiency of its personnel. To his mind nothing could be better for a firm than to have a good smattering of its own apprentices to rise from the ranks.

With regard to the curriculum laid down for the course of instruction, the first two years were drawing and elementary science. They might teach with advantage other subjects. For instance, there was quite a lot that could be taught to a young man on general workshop methods, so that if he happened to be working a certain class of machine, he could at least see other things that were going on around him.

Mr. Verry said that he found in these days of speed, when a job was wanted so quickly, he could not give a boy the job to do, whereas, when he was going through the shops, there seemed to have been a little more time. Boys were apt to be neglected to-day by their supervisors as regards moving them about. That had been a very serious problem to him, and he felt it was his responsibility to give them a training which would fit them for life when they had left the works. A certain amount of education in workshop practice could be given in the technical institute. For instance, a boy might be given a training on a lathe, screw-cutting machine, etc., which might be useful to him in the shop. It was his view that the technical institute could do a lot to pioneer work in training the boys on the machines in workshop practice. They might have six months on a milling machine, etc. That, in his opinion, was what the technical institute could do to help supervisers in the factory as regards training the apprentices and craftsmen. Again, a knowledge about the material used was often of the very

utmost importance. Grinding was another field. Probably ninety-nine out of a hundred men working on a grinding machine to-day had no knowledge what they might do with the steel they were grinding. There was quite a big field in that subject, and it could be extended to familiarise the young man's mind with the actual cutting of the material. He was very much surprised to hear Mr. MacLachlan's figures—that there were so very few who came to the technical college from the shops. Not only were there very few, but they dwindled off, and you could not get the lads. It was not always the fault of the works managers. In his opinion it was lack of keenness. The great thing they had to do first of all was to arouse some interest in the lad in the profession or craft in which he was endeavouring to make himself an expert. If one went further back, not only to the elementary school, but also to the public school and the grammar school to-day, one seemed to get the idea that the lads could do as they liked. Unless a lad learnt to obey he was not likely to do much good. They seemed to be working on the lines that just the opposite was the case. Take also, the question of coming to the technical college. Even the lads that came—his firm give their lads the time off but that was not sufficient—they have to be paid to come. Yet, if he had not got keenness his education was not worth twopence! The great question was how they were to get keenness into the shops? The modern youth wanted a lot of pleasure. During the winter time there were such things as dancing classes, and his experience was that the average lad would sooner go to a dancing class than to the technical institute. Lack of keenness—that was the thing!

Mr. Clark said that as regards the instruction in the course in workshop practice at the technical college, he regretted that the response so far to the technical side of the work had been very poor. He wanted to stress that particularly before a body of men engaged in machine tool and other operations, and if they could induce their students to attend the course, they would be very pleased. A feature of the work which their principal had mentioned was the three years' course working right up to the Ordinary National Certificate of the Mechanical Engineers. The examination at the end was by no means the most important feature. It was the continuity of the whole course that was important. The past forty years had seen many changes in the method of training engineers as distinct from craftsmen. The college trained the engineer. Every sane employer realised that the training of young men could not be undertaken lightly and without motives of expediency. As to training a young man for what might be called the engineering profession as distinct from craftsmanship, when his boy was leaving school at sixteen he sent him into the workshop and said to him, "If you are going to be an engineer, and if you want to get more training, you can go on with it." He had had

the advantage of the shop, the technical school, and he was going to Birmingham University. He believed that the training given could commence at a later age than sixteen, if a boy had continued his schooling to that age. Their principal had indicated that the Ordinary National Certificate line of work represented a very good basis of training for a student who wanted to specialise in engineering. They were doing reasonably satisfactory work in the technical college, but some day it would come home to them that they had neither room enough nor equipment enough for doing it. And he wanted Coventry to know that.

A VISITOR said that, having just finished his apprenticeship, he felt that there was great need for the young engineer to be furnished with information as to suitable literature. For instance, there was a very valuable book on aeroplanes which would have been of great assistance to him. He thought it was the duty of his firm to have pointed it out to him and enabled him to buy it, and he also thought it should be a function of the Institution of Production Engineers to give advice as to suitable books on all production subjects.

After further discussion, a vote of thanks to the Principal, Mr. MacLachlan, concluded the proceedings.

MODERN FORGE MACHINERY AND DROP FORGING DESIGN.

Paper presented to the Institution, London Section, 27th March, 1929, by Captain F. W. Spencer.

IN choosing a title for this paper that would be comprehensive enough to cover anything that might be said about the various methods and processes carried out by the drop forger, it was felt that a word or two about the design of components which are to be forged in dies would be of interest to many production engineers. Speaking as a drop forger, it seems as if very little thought is given to the design of components which are to be forged. This statement is not to be taken as a reflection on designers and works' managers, but should, I think, be shared with the drop forger who has never made any serious attempt to educate the user of drop forgings in the scope and limitations of the art from an economic point of view.

The usual procedure whenever drop forgings are required is for the buyer to send out broadcast enquiries with the machine shop prints of the components, and a request that prices be sent in by return of post for lots of 100 to 5,000 or more. The prints usually indicate where machining is to be allowed for, but rarely stating how much should be allowed or how it is proposed to commence the machining operations, or what toleration on the various dimensions will be accepted, neither are the jigging points indicated. The result of such an enquiry being that whoever gets the order, may be faced with a lot of trouble in supplying the forgings with the necessary accuracy to enable the machine shop to commence machining without gauging one or more particular dimension.

The modern drop forger has so many machines other than drop hammers at his command, each of which has special and peculiar characteristics, that I propose in the short time available to touch the outstanding points only. In my opinion the order of importance of the various machines in a drop forger's works should be as follows :—

> Forging or upsetting machines ; drop hammers ; friction screw presses and crank presses ; swaging hammers (Ryder's and Bradley's) ; taper rolling machines.

I should perhaps have stated that to my mind the drop forger should be able to produce a forging in any material that is forgeable, and here I might state the name " drop forging " is really a misnomer, in view of the many machines which are not drop hammers on which forgings are now produced. A forging or upsetting machine is similar to a horizontal press with a movable die in place

of the press table, with mechanism to open and close the die at a certain definite time in relation to the stroke of the ram. To the ram are fixed punches or heading tools which enter the dies and squeeze the metal into the die impressions.

Drop hammers are divided roughly into two types, first of all in the gravity fall type in which the hammer is raised by steam or compressed air, or by frictional device in connection with a constantly revolving shaft. The second type is one in which the hammer is raised by means of steam or compressed air acting directly on the piston, to the rod of which the hammer is fixed. In this type the steam usually acts on top of the piston, so that the force of the blow is many times greater than the force due to gravity alone.

The friction screw press consists of a vertical screw working in a thread cut in the frame of the machine ; the head of the screw is keyed to a flywheel which has some friction material attached to the rim, and is situated between two constantly revolving discs, which, by means of a hand lever, can be brought into contact with the rim of the wheel. By this means the screw is raised or lowered, and the upper die which is attached to the lower end of the screw can be brought into contact with the heated blank which has been placed in the lower die resting on the bed of the machine. It can easily be seen that the operator has at his command a tremendous force when it is realised that the flywheel, revolving at a speed of some hundreds of revolutions per minute, is brought to rest very quickly when squeezing the metal into the impression in the die.

The crank press used in forging or pressing work is very similar to the ordinary crank press used for sheet metal work, which is no doubt familiar to everyone. Ryder hammers are, I think, peculiar to England, and were developed mainly in Lancashire to produce the many spindles used in cotton machinery. Swaging hammers, such as the Ryder, are, in reality, multiple crank presses of very short stroke running at high speeds with swaging dies or tools fixed to the rams, between which the bar resting on the fixed bottom anvil is reduced or shaped, depending on the design of the swaging tool. In the Bradley Helve hammer, which is also run at a high speed, there is only one pair of dies which limits the range of work to a certain extent. Taper rolls are similar to ordinary hot rolls except that the rolls usually carry dies fixed to their periphery for half their circumference. The rolls revolve towards the operator, and at every half revolution the operator thrusts the bar forward, where it is gripped between the die faces and pushed towards him. The grooves in the dies are gradually decreasing in depth and section, and so produce a taper on the bar as it is passed through.

Having briefly described the various types of machines used for

producing forgings, I will deal with some of the limitations to which they are subjected, as it will be easily understood that a design for an article to be produced on one machine might be not at all suitable for another. A gear blank, for example, if produced on a drop hammer, would be designed in one way, the "draw" or "leave" of the dies and the solid boss necessitating a large amount of machining. If this was to be produced on an upsetting machine, it could either be left solid or the centre hole in the boss could be punched out.

There are economic limitations in the size of a gear that can be made with a punched centre hole, as the diameter of the hole in a great measure determines the size of the bar from which the gear is to be made. In the case of a large diameter gear with a small hole, the amount of material to be gathered necessitates a large number of gathering operations which, in turn, requires larger dies. Another limiting factor is that for economic working the gear should be produced at one heat, and to do this it is rarely possible to use more than two or three gathering operations followed by one punching operation. A feature of a forging which has been punched off the bar is that the punched hole can be held to very close limits, and it is possible to broach the hole without any previous machining operation, as owing to the lower temperature at which it is punched the walls of the hole are clean and free from scale.

[*Here the author gave the following illustrations*:—(*a*) *A roll end made on an upsetting machine from a* $\frac{7}{8}$*-inch diameter bar. Three gathering operations are required and two expanding operations*; (*b*) *The dies used for producing gear blanks on an upsetting machine, the hourly rate of production being from* 60 *to* 70 *per hour*; (*c*) *The dies for producing a steering column housing, the output being* 50 *to* 60 *per hour*; (*d*) *The saving in weight of metal used, and also in the amount which has to be machined off the forging in the case of a small sleeve pinion.*]

The details of manufacture are given in parallel columns.

	DROP FORGED ON A 15-CWT. DROP HAMMER (UPENDED).	UPSET ON A 2-INCH UPSETTER.
Gross weight of material used, each	$3\frac{1}{2}$ lbs.	$2\frac{1}{4}$ lbs.
Weight of trimmed forging ...	$2\frac{1}{4}$ lbs.	2 lbs.
Production per hour (average) ...	50 to 60	90 to 100

The saving of 1 lb. of steel, apart from the necessity of heating this amount of material, and with the reduction in labour cost coupled with the greatly increased output, effect a reduction in ultimate cost of over 33 per cent. It is not possible to effect such a reduction in cost on every job which is taken from the hammer to the upsetting machine, but even where no reduction is made in

the first cost, the saving in the cost of machining is often a considerable item. I could go on enumerating innumerable examples of a similar kind, but I think I have given sufficient illustration of what can be done by collaboration between those responsible for the machining and the producer of the forgings. In many cases components which have been produced as malleable castings with all the difficulties of machining, can be made on the upsetting machine at no greater cost but with much better machining properties.

Without giving a large number of sketches it is difficult to deal with the design of forgings which are to be produced on a drop hammer, but one or two examples may be given which will indicate in a general way the points to be considered. Connecting-rods are often designed with extremely thin flanges on the " H " section, which, besides being extremely difficult to produce, are a source of weakness as any scale forming on the edge reduces the sectional area at that point.

The variations in a drop forging are generally in the direction the dies meet, although a toleration of plus or minus $\frac{1}{32}$-inch should not be exceeded. In the other directions, unless there is a considerable flow of metal taking place over the die face, the shape should be maintained for some few thousand forgings before they become too heavy. As a practical commercial limit the weight variation of a connecting-rod stamping weighing between 5 and 6 lbs. can be maintained at plus or minus one ounce.

The design of drop forgings to be produced in high tensile aluminium alloys follows generally those for steel except that the angle of " leave " should not be less than 10 degrees, and all corners should be well rounded. This metal at its forging temperature does not flow so readily as steel, and behaves more like steel at a temperature of 750° C., so that it can be readily seen that much heavier blows are required than when making a steel forging of similar size.

While it is usual to use oil or coal fired furnaces for heating steel billets for forging where the working temperature range may vary from 900 to 1,050° C., it is necessary to maintain a temperature between 430 to 460° when forging aluminium alloy, and to do this it is necessary to use electric furnaces which have full automatic temperature control : this automatic control when once it has been set, absolutely ensures that the material cannot be over-heated, a variation of plus or minus 5° C. never being exceeded.

As this aluminium alloy only attains its high properties by heat treatment, the electric furnace is ideal for this work although for small work salt baths can be used.

In conclusion, I wish to thank The Birmingham Small Arms Co., Ltd., for their permission to describe the methods and processes outlined in this paper, and to thank my colleague, Mr. E. S. Collett, for his assistance in preparing and arranging the drawings in connection with it.

Discussion.

Mr. E. D. Ball (Hon. Secretary), speaking with regard to the limits on the upset gears illustrated by the author, asked what was the limit of the bottom hole, on the bore and the outside diameter and whether the metal on the outside was hardened in any way to prevent cutting of the teeth and satisfactory performance afterwards.

The Author said that the limits on the gear made by the upset machine were uniform, which was an advantage for a drop forging. It cut out the personal element and ensured the same amount of material going into the die. There might be slight variations in the diameter of the bore, but in practice it was found that forgings from upset machines were very uniform. The outside metal was not hardened in any way apart from the hardening that was applied to any other part of the gear. The metal was squeezed into position in the die and it was the usual practice to leave $\frac{1}{16}$-inch or $\frac{1}{8}$-inch to be machined off, to allow for the fact that some steels have more scale than others. As to the bore, owing to the fact that it was punched out, a very smooth hole was obtained if the punches were kept in good order, as would be seen from the examples he had on view.

Mr. Weatherley asked for information of the relative cost when using dies with the upset machine as compared with the drop stamp. The author had remarked that he only got 1,000 forgings from a die before it had to be renewed. In the case of con. rods, that might mean renewing the die every day.

The Author replied that it was a slip if he had said the die had to be renewed after every 1,000 forgings. The number was usually considerably more than that, although it depended upon the nature of the article and the exact method employed in the die. Some of his dies gave 16,000 or 20,000 forgings. If the order was only for 250 or 500 articles, then it would not be worth while making a die with multiple impressions. As to the comparison of cost referred to, again a great deal depended upon the type of article and it was difficult to give a comparison of a general character without knowing all the details of a particular article, and then the comparison would only apply to the particular case.

Mr. Sumner asked if the author could give any idea as to how far forging manufacture would solve the chip problem in the machine shops. It had been stated at the Machine Tool Exhibition that this very serious problem has not yet been satisfactorily solved, and he was wondering whether the author could say to what extent forging would relieve machining operations.

The Author said this was largely a question of economics. It was easy to make a forging which had a lot of material on it if it had not to be particularly accurate. If a very accurate forging was required, then it would have to be made in a multiple operation

die and subject to the limitations of designs it was necessary to have a 7° taper on all the outside edges. If a smaller angle was used, the dies would stick by friction and the operations would be slow and unsatisfactory. That was the only way to get very accurate work.

MR. WHITWORTH asked the author's views as to the desirability of allowing drop forgings to go from the smith's department to the machine shop without normalising.

THE AUTHOR said he had not mentioned heat treatment in the paper, but his view was that without exception forgings in steel should be either normalised or annealed or heat treated in some way after forging to relieve the strains and prevent subsequent distortion.

MR. WEATHERLEY asked for information as to the relative merits of the friction screw press and the crank press for hot brass.

THE AUTHOR replied that he had had no experience of the crank press for making hot brass pressings although he had seen it done. On the whole he thought the crank press was probably quicker than the friction press for hot brass pressing and for making symmetrical pressings such as small sleeves. The friction screw press, however, was a more universal machine. There was a bigger die space and it was possible to get round the machine better and generally to do a bigger range of work. It probably required a little more skilled operator to work.

MR. PUCKEY asked whether the drop forger had any preference in regard to putting holes in parts. For instance, the author has shown a hub which at first had a hole part of the way through and afterwards was made solid, and he was wondering whether this was due to a preference on the part of the drop forger. He felt that this question of putting holes in drop forgings was often overdone and that the parts would be better left solid more often than was the case It would be interesting to know the relative cost of a particular article produced by the upset machine and by drop forging, quite apart from the cost of the die, because there were so many problems due to the shape of the pieces that caused trouble and tended to keep speed of operation down. If it were possible to get things with parallel faces it would increase the feed and speed fairly considerably. If therefore this could be done, as in the case of the upset machine, without increasing the cost to any appreciable extent, of the forging or stamping, it would be very welcome and the machine would be more widely adopted than it was at present.

THE AUTHOR said the advantage of the upset machine was that it lent itself to parallel faces with outside diameters whereas with drop forging it was nearly always necessary to have taper faces, and it was therefore difficult to get a very good grip in the jig. As to holes, there might be differences of opinion about broaching. In his own case the broaching was not done in the works but by

the people who supplied the parts he had exhibited in large quantities, say, 5,000 per annum. There seemed no difficulty about it, however. One of the parts exhibited was of heat-treated steel to about 24 tons and 269 Brinell, and at that hardness there did not appear to be any difficulty in broaching. As to relative costs of forging and the use of the upset machine, in the case of one sleeve —also exhibited—there was a saving of 1 lb. of metal in the amount required when using the upset machine. That steel cost £35 per ton and there was 3d. saved in metal per article alone and there was $\frac{1}{4}$-lb. less to be machined off, so that there was a considerable economy over drop forging. Therefore more consideration should be given to the upset machine, especially in the case of gears where every tooth was required to be as strong as the other. Another point in connection with the upset machine was that the grain of the metal was in the direction where it gave the greatest strength, whereas with drop forging, unless it was corrected afterwards in the drop hammer, the grain was at right angles and therefore in a very bad direction for resisting shock. As to the preference of forgers for holes, the position was that as a rule those ordering the parts specified where the holes were to be, the only reason being to reduce the amount of metal required for the job. Most people specified, in the case of the hub exhibited, that the hole should be on one side and not on both, although sometimes it was specified that the piece should be solid. It all depended on the buyer.

Mr. Clarke asked what material was used for the dies on upset machines.

The Author said that a great variety of metals could be used. Heat-treated nickel chrome dies were used for drop forging, and it could also be used for the dies in the upset machine. Actually, he had got the best life from chrome-vanadium steel in the forging machine with a carbon content of about 40 to 45 per cent., 1 to $1\frac{1}{2}$ per cent. of chrome and a small percentage of vanadium. Such dies stood up well. They were quenched at 870° and tempered at about 500°, and then they went straight into the machine after being put on a surface grinder to square them off. For drop hammers, the British Standard Specification No. 3 nickel-chrome was used, containing 55 to 60 per cent. of carbon and $1\frac{1}{2}$ per cent. of chrome. Such dies gave long life with drop hammers. The die steel used by many forgers contained 1 per cent. of nickel and about 60 per cent. of carbon, and in the case of large quantities of the same article it paid to use the best material for the dies and to go in for a more elaborate die.

Mr. Weatherley asked which materials, other than steel, lend themselves best to forging. The author had mentioned aluminium alloys.

The Author said that 60/40 brass, duralumin, and the aluminium alloy he exhibited, were easily forgable materials. There was also

manganese-bronze, nickel, silver, and copper, but the usual metals were steel, brass, and aluminium. One of his specimens was an alloy of 4 per cent. copper together with aluminium and a little manganese. This had a tensile strength of 23 to 26 tons, 16 to 18 tons yield, and about 20 per cent. elongation. In forging this material, it was important to keep the temperature within certain limits. If it went beyond 430 to 460° the metal crumbled, and if it went lower an enormous pressure was required to forge it.

MR. SUMNER asked what is the relative cost of forging in duralumin and steel. Possibly the dies would not require to be so strong for duralumin or aluminium alloys as for steel.

THE AUTHOR said it was much more costly to forge duralumin or aluminium alloys than steel and where the question of cost entered into a job it was hardly worth while considering aluminium alloys because the cost would be 2½ to 3 times that of steel, and even that was cutting it rather fine. Much the same applied to forging duralumin. It was all a question of whether the particular job would be worth the extra cost.

MR. SUMNER asked whether the extra forgability of duralumin or aluminium alloys would be an asset inasmuch as a larger number of pieces could be made per day.

THE AUTHOR said his experience was that duralumin and aluminium alloys are not so easy to forge as steel. A heavier hammer and a larger number of blows would be required as compared with steel. The plasticity of aluminium at forging temperature was about equal to that of steel, say, at a temperature of 750° C., but it was not half so plastic as steel at the forging temperature of steel. On the other hand, duralumin or aluminium alloys were not so abrasive as steel and did not wear the dies to the same extent.

MR. BUTLER (Chairman) asked how an axle made of 23-ton tensile aluminium would compare with a forged steel axle.

THE AUTHOR said that a front axle in steel would never be made of material less than 40 to 50 tons tensile, and therefore with a 23-ton aluminium alloy, the section would have to be increased. Aluminium was roughly one-third the weight of steel, but owing to the increased section the final weight of the aluminium axle would be about half that of steel but the axle would be stiffer.

MR. ZIECHANG asked whether gas- or oil-fired furnaces were the cheapest in relation to forging.

THE AUTHOR said the furnace question became an acute one during the strike when neither coal nor coke could be obtained. Many people then went to oil and had continued to use it, including his own firm. Although he had not complete figures with him he believed that oil furnaces should be slightly cheaper than coke-fired furnaces. At the same time there were people who liked coke and thought there was nothing like it, but it was more a matter of

convenience than anything else as to which type was used. With coke furnaces quick heats could not be obtained, whereas with oil fired furnaces quick heats and intense heat were the feature, and the heating could be obtained fairly locally, and that was what was wanted with a forging machine. His own feeling was that oil furnaces, properly looked after, would be the most effective and economical for steel. In the case of drop forging, quick heating was required, and from that point of view electric furnaces were useful. Ford had a shop containing 27 upset forging machines running in conjunction with electric furnaces, and although he, personally, had not seen them he had been told by people who knew something about them that they were not very perfect owing to trouble with the elements. Nevertheless, Ford persisted in using them and we should know more when reports came over of the working of these furnaces. His own firm used electric furnaces for melting aluminium alloys, but in that case the temperature was very different and it was a simple proposition. The temperature was not above 460° C., but it was a very difficult matter to find a refractory that would stand a temperature of 1150° C. However, the electric furnace people were working on that problem at the moment. Another method of heating bars for the forging machine was by a machine similar to that used for electrically heating rivets. The bar was clamped between large copper electrodes and heated in that way. That was a suitable method for small bars, but for larger bars the heating was not quick enough. The high frequency electric furnace was used for melting steel, and possibly something of that sort might be used for heating bars. Indeed, he had an idea that this was being worked on now.

A MEMBER said he saw no reason why fair size bars should not be heated sufficiently quickly for forging purposes by means of low voltage electric furnaces. By this means it was possible to heat up quickly, and if they were a little ahead of the forging machine it was possible, by means of the method of control, to hold the heat sufficiently for a short time. He had not had experience of that with steel. but he had done it with aluminium without damaging the metal. For bars up to $1\frac{1}{2}$-inches he imagined the electric method would be quite successful. Very fast work seemed to be done on the machines in the Ford factory, which he had seen, and if the method was economically successful it did not matter if the elements had to be replaced frequently or not. There need be no limitation as to the amount of heat obtained by the electric method.

THE AUTHOR said he did not think the electrical people had really got down to this problem yet. He agreed that so long as the output was required it did not matter if the electrodes had to be replaced frequently. At the same time, the electric furnace had not been pushed for forging in this country. These machines were

being experimented with in America, and he hoped some of them would be brought over here for trial.

MR. E. D. BALL (Hon. Secretary) asked whether there was any information with regard to the silence of gears made by means of the upset machine. With the forging machine presumably there could be all sorts of weird effects if the dies were not in proper alignment. He had recently come across a case of gears manufactured under very scientific conditions and to an accuracy of 1/10,000th inch, but yet he was told they sometimes came across noisy gears.

THE AUTHOR said he could not say whether gears made on either machine were more silent than each other. As a matter of fact he knew very little about the gear question, although he knew how difficult it was to make a silent gear.

THE CHAIRMAN commenting on the remark by the author as to the importance of personal attention in regard to the supply of forgings, said that that point could not be raised too often. It applied very largely to castings and also to all kinds of pressings and forgings. The thing which must be realised was that only really good results can be obtained by the people responsible getting down to the job personally. When a large number of pieces were required, somebody in a position to discuss the matter from a technical point of view must be sent to interview the forging or foundry people and show exactly what was wanted before the drawings were prepared. That was far better than spending weeks writing letters endeavouring to make the position clear. It was often possible, by having a chat in this way to suggest methods of doing the work which might cost a few shillings per cwt. less and it was a far more satisfactory method than the more usual one of inviting prices from all the firms that could be found and carrying on the whole business by means of correspondence.

On the motion of Mr. Weatherley, a hearty vote of thanks was unanimously accorded to the author for his paper.

HEAT-TREATMENT FROM THE PRODUCTION ENGINEER'S STANDPOINT.

Paper presented to the Institution, Birmingham Section, 10th April, 1929, by C. M. Walter, D.Sc., A.M.I.E.E.

IN considering the question of heat-treatment of metals from the production engineer's point of view, it would perhaps be best to have a clear conception of what is meant by heat-treatment operations generally, more particularly those operations under the headings of hardening, tempering, annealing, normalising, carburising and re-heating. It is interesting to note that in practically every manufacturing operation, thermal treatment in some form makes itself evident, and during the past ten years, the heat-treatment of such components as are used in the production of motor cars, machine tools, aeroplanes, and practically every engineering structure, has become one of the most important processes which the material has to undergo during the various stages of its being worked up into the finished article.

Some few years ago, mild steel and medium carbon was used to a great extent for production of engineering components, the material was considered to be satisfactory if utilised in the normal state, after being soaked for a long period and allowed to cool slowly in the furnace, this treatment bringing about an annealed condition imparting to the material ductile qualities which enable it to be freely worked, but at the same time resulting in a tensile strength being obtained which was far below the requirements of the present day.

Thus it will be realised that the importance of heat-treatment of steel components has come about owing to the necessity for obtaining from any material the maximum resistance to stresses which are imposed upon it, enabling the amount of material required for a component to be reduced to an absolute minimum. The importance of this can be fully realised when considering engineering structures such as aeroplanes, internal combustion engines, and similar work.

I will now refer briefly to various heat-treatment operations to which ferrous material is submitted, such as are usually met with in heat-treatment shops, all of which must receive the most careful consideration of the production engineer, and later, I will deal more fully with factors which have to be taken into consideration in all heat-treatment operations, and also the question of the design of

furnace plant suitable for such heat-treatment operations. The heat-treatment operations most generally met with may be classified under the following headings :—(a) Annealing, (b) hardening, (c) tempering. (d) normalising, (e) carburising or case-hardening, (f) re-heating and quenching after carburising.

Annealing.

The process of annealing consists of the heating up of material to some pre-determined temperature and then allowing to cool down at a moderately slow rate. The object of this treatment may be either :—(1) To produce a refining of the structure of the material which may have been coarsened by over-working or over-heating, or (2) to remove internal stresses which have been produced in the material by mechanical work performed on it.

Where material is annealed to remove internal stresses and to produce softness and greater ductility, the temperature to which the material is raised will not necessarily be the same as in the case where the material is annealed to refine the structure, as in the latter case, it is essential that the material be heated to a temperature above the upper critical point of the material, as only in these circumstances would the original structure of the steel be altered.

Hardening.

The process of hardening consists of heating the material to a definite temperature which depends upon the composition, after which the material is quenched more or less rapidly in a suitable medium such as water, brine or oil, or in some cases, in special fuse salts. In the case of high speed or air hardening steels, either oil quenching or the rapid cooling of the articles in still air or air under pressure, results in sufficiently rapid cooling for the retention of the carbides present in the steel in solution.

Tempering.

The process of tempering is one which generally follows a hardening process, and is carried out by raising the material to some pre-determined temperature below the hardening temperature to modify the structure produced in the steel by the quenching operation, this leading to an increase of toughness and usually to a reduction in the hardness of the material. This operation is carried out usually by heating in an open furnace, or in oil or salts, to the desired temperature, after which the steel may either be cooled slowly or quenched in oil or water, as following the hardening treatment. It might be well to point out here that the time element is an important factor in tempering operations.

Normalising.

One of the most important preliminary treatments applied to steel forgings used in the manufacture of aircraft, automobile

components, and also tools, dies, punches and similar components, is normalising to bring about a refining in the grain structure, and still leave the material in a soft state, in a readily machinable condition and uniform in its structure. This operation is generally carried out by raising the temperature of the steel to a temperature slightly higher than the upper critical point, allowing it to cool freely in air at a moderately slow rate. Normalising is also resorted to in many cases to relieve internal stresses produced in material owing to previous heat-treatment or working, and differs from annealing in so far that it improves and refines the grain structure of the material.

Carburising or Case-hardening.

The carburising or case-hardening of steel, often referred to as a cementation process, depends on the absorption of carbon by steel of certain composition when raised to a sufficiently high temperature in contact with carbonaceous matter, usually in the form of a carbonaceous gas evolved from the carbonaceous material in which steel is packed. The case-hardening process is usually followed by the re-heating treatment, during which the steel components, after being cemented in the manner mentioned above, are quenched after heating to definite temperatures one or more times, with a view to refining the material and also producing the necessary hardness of the surface so carburised.

It will be understood that by the carburising operation, it is possible to produce hard wearing surfaces by increasing the carbon content of the steel on the outside layers, and at the same time retain a ductile and fibrous core, which is more capable of withstanding the combined stresses to which such parts are usually subjected.

The steels most commonly used for carburising consist of straight carbon steels having carbon contents of .15 to .2 per cent., nickel steels containing 3 per cent nickel and .15 to .2 per cent. carbon, nickel steels containing 5 per cent. nickel and .15 to .2 per cent. carbon, and also nickel chrome case-hardening steels containing up to about 4 per cent. nickel, 1.3 to 1.4 per cent chromium and about .15 per cent carbon.

In the carrying out of the case-hardening operation, the material is usually packed in a carbonaceous material in sealed boxes, consisting either of steel or special alloy, and allowed to soak in the furnaces at temperatures from 900 to 950° C. for a period the duration of which will depend on the depth of case required, the carburising material used, the carburising temperature and the analysis of the steel. After the carburising operation is completed, the pots are usually allowed to cool slowly in the furnace, and after cooling slowly to a certain temperature, the work is removed and

re-heated to produce the refining of the core and the hardening of the case, as previously mentioned. In cases where it is not essential to retain the toughness of the core, a single re-heating of the material is sometimes sufficient, but where it is essential to retain the ductile properties of the core, it is necessary for a further treatment to be given to destroy the growth in the crystal size which has been promoted by the slow cooling from the carburising temperature.

I do not propose in this paper to go deeply into the technicalities associated with the various changes in structure brought about by heat-treatment, as this in itself forms the subject of a separate paper, but I have merely outlined above, under headings, those processes which one will generally find being carried out in any modern heat-treatment shop.

With regard to the more important questions which have to be considered from the production engineer's point of view : I wish to enumerate a few of the more important factors which must be taken into consideration in every type of heat-treatment operation, and factors which, to a great extent, determine the ease with which a steady flow of properly heat-treated material, uniform in quality and free from defects, can be relied on. In the first instance, it is most essential that the lay-out of the heat-treatment shop should be such as to enable proper ventilation to be obtained ; the shop should be well lighted, preferably by roof lighting, and the furnace plant should be installed, where possible, in such a manner as to prevent direct rays of light entering the furnace chambers.

An ideal lay-out for a furnace shop is undoubtedly one in which the whole of the furnaces are arranged in single lines on one side of the shop, whilst the space on the opposite side, which is well illuminated by daylight, is used for the preparation of work prior to heat-treatment.

Whilst, as will be mentioned later, it is absolutely essential that some form of pyrometric control of temperature should be allowed for, it is necessary that the uniformity of the heating of the furnace chamber can be checked by the eye of the operator, with a view to ascertaining whether there is any uniformity which the pyrometer may not take into account. It is a well-known fact that a skilled operator is able to judge variations in temperature very accurately, provided that his observations are not impeded by effects of sunlight entering the furnace door, hence the importance, where possible, of arranging the furnaces so that daylight cannot directly enter the furnace chambers. With regard to the passing of work through the furnace shop : as in all other operations, it is essential that the material should move in one direction, and in a well-designed hardening shop, arrangements should be made whereby the raw material is received in the stores adjacent to the hardening shop and after inspection and detailing out, passes through the shops in

one direction, eventually passing from the hardening shop into an inspection room, hence to other departments.

With regard to inspection and testing: whilst it will be generally agreed that any hardening shop should work in conjunction with a laboratory, it is essential that the inspection section of the shops should include in their equipment, certain testing appliances. These should include a Brinell testing machine, either of the ball type or diamond type, and if possible, some form of optical projector, by means of which Brinell impressions could be quickly and readily read.

Up to the present time, the writer has not found any apparatus which is all that is to be desired for the testing of heat-treated components on a production basis, but it would seem that there should be no difficulty in fitting up an apparatus consisting of an inverted microscope in conjunction with a projector to enable Brinell impressions to be magnified up and the image projected on a screen where it could be readily measured. This type of apparatus would have the further advantage that any forging or component would only require grinding on one face, after which it could be placed on the microscope table without any need for setting up as with the usual apparatus. The inspection department should also include as part of its equipment, at least one standard thermo-couple, in order that thermo-couples used in connection with the various pyrometer outfits could be checked from time to time. The checking of this reference couple would in its turn be carried out by the works laboratory periodically, so that by this means, the hardening shop would also have by it a sub-standard for reference.

Other factors which are of equal importance include the proper disposition of the water or oil quenching tanks, as the case may be, in regard to the furnaces, and whilst ample room should be given for operators working on furnaces, it is essential that the quenching tanks be placed as near as possible to the outlets of the furnaces, in order that the temperature drop during the period of removing from the furnace to the tank is a minimum. It is equally important that proper cooling facilities are provided, both for water and oil, as it will be often found that in large shops handling large quantities of material, difficulties are experienced at the end of the day, owing to water or oil temperatures being so high as to prevent the work being cooled sufficiently rapidly to give the desired results.

Many excellent types of cooling plant are available, some of which depend on the circulation of the medium to be cooled, through pipes, water-jacketed or brine cooled, and in other instances, the heat is extracted from the medium by passing cold air over the water or the oil, as the case may be. A typical example of this latter type of plant is the Heenan & Froude oil cooling plant, which

depends on the air cooling of the medium, whether it be oil or water, which is arranged by means of a fan casing cold air to be passed over a metallic mat, through which the medium to be cooled is passed.

With regard to the importance of accurate temperature regulation and control, in all heat-treating operations, this cannot be too strongly emphasized, as on this depends, to a great extent, the quality of the work obtained. Most hardening shops are now fully equipped with suitable pyrometers, and in the case of very large shops, where the automatic handling of goods is resorted to, it becomes necessary to install automatic control gear, to enable the temperature of the heating chambers to be kept within definite pre-determined limits. Where a number of these automatic controllers are in use and used in conjunction with temperature recorders, it would be advantageous, where possible, to arrange this apparatus in a special room, so that one observer would have the whole of the control under his observation. This method is adopted to a very great extent in America, and has proved an undoubted success.

With regard to thermo-couples : I am of the opinion that in view of the possibility of deterioration of any thermo-couple after being in use for a certain period, where possible, at least two thermo-couples should be used in each furnace, and it is advisable, in such cases, to have the second couple put into operation some considerable time after the installation of the first, so as to ensure that at all times, at least one couple is in satisfactory condition.

With regard to temperature recording and control : I am of the opinion that it is essential that any recorder used in conjunction with the furnace should also be associated with an indicator placed near the furnace, so that the operator can at all times check his temperatures, and further, it is generally advisable for the furnace operator to have periodical access to the recording instruments, so that he can make himself acquainted with the variations which are taking place in temperature over a definite period.

With reference to automatic control : I am glad to know that many excellent forms of auto controllers are now being placed upon the market capable of operating and controlling gas furnaces and maintaining temperatures within very fine limits of variation. It is often found advantageous to associate with controllers of this type, auto time switch gear, which enables any furnace to be let up automatically at any pre-determined time. This system is often made use of for lighting up furnaces on Sundays after closing down during the week-end, so as to be at a working temperature on Monday morning, and with suitable bye-passing arrangements, control of this kind presents no difficulties at the present time. Another important factor is the control of the atmosphere within

the furnace chamber, and I propose to deal with this later, when considering furnace design.

Designs of Furnaces Suitable for Various Heat-Treating Operations.

In the majority of heat-treatment shops, furnaces fired by town's gas are used to a very great extent for the bulk of heat-treatment operations, although, of course, other forms of fuel can be used, including producer gas, oil and solid fuel. Town's gas has been almost universally employed owing to the many advantages obtained by its use, including ease with which the fuel can be completely burnt, cleanliness, convenience, and also the further advantage that the atmosphere within the furnace chamber is under the complete control of the operator. There are also the added advantages of ease of temperature control, adaptability to automatic control, small floor space required, low first cost, and also the ease with which the fuel can be metered for purposes of costing. Further, it will be generally found that the first cost of a modern town's gas-heated furnace will compare favourably with many other types.

With regard to efficiencies obtainable from furnaces of this type, it will be generally found that where the work is of an intermittent nature, in which case usually a furnace of low thermal capacity is employed, in order that the period of heating up and the fuel consumption is not excessive, efficiencies of about 20 per cent. are readily obtainable without any form of recuperation or regeneration, but in the case of larger furnaces which are used more or less continuously, it is generally found that the recuperator type of furnace is the most efficient form to employ, the amount of recuperation depending on the length of the period during which the furnace is in continuous use each day, and also on the nature of the loads required to be heated. This form of furnace usually has a moderately high thermal capacity, and hence, after shutting off at the end of the working period, a considerable storage of heat takes place in the massive brickwork, which maintains such a temperature in the furnace as to enable it to be quickly brought up to the working temperature when again required for use.

Furnaces of this type are usually very carefully lagged with first-class lagging material, and I would here like to mention the importance of this matter, as in many instances, an increase in efficiency of not less than 10 per cent. can be attributed entirely to effective lagging. Another important point in the design of such furnaces is that the doors should be well lagged and well fitted, so as to reduce the leakage to an absolute minimum. It is also essential that efficient damper control should be arranged for, so that the pull on the outlet can be regulated in accordance with the amount of gas being burnt in the combustion chamber.

Efficiencies as high as 55 per cent. have been obtained from

furnaces of this type working continuously, this figure of efficiency representing the ratio of the amount of heat usefully employed in raising the load to a given temperature to the total heat units supplied, it being assumed that the furnace setting itself has been previously heated up to a working temperature.

For high temperature operations, such as the treatment of high speed steel and forging operations, where temperatures ranging from 1150° to 1400° C. are required, the most usual type of furnace employed is one in which gas at ordinary pressure is used in conjunction with air under pressure of about 2-lbs. per square inch. With such types of furnaces working continuously, efficiencies of 25 to 30 per cent. can be readily obtained. In the case of re-heating, hardening, and tempering, it is usual to employ town's gas at a low pressure of 3 to 4-inch water gauge with atmospheric burners, and with this type of furnace, any temperatures up to 1000° C. can be readily obtained.

During recent years, the automatic handling of work through furnaces has received serious consideration by furnace manufacturers, owing to the ever-increasing demand for this type of furnace for dealing with standard components such as are used in the automobile and other industries, and already, a large number of furnaces of this type, by means of which work is automatically carried through the furnace, raised to the desired temperature and quenched, are now being used. For many years, it has been customary in America to make use of this type of furnace on a large scale, and I am glad to say that several excellent designs have been produced by English firms, and already, a large number of these furnaces are in continuous operation.

With regard to the use of gas seals in furnace chambers, it has been found very beneficial with certain classes of work to prevent excess of air to the hardening chamber during the heating up of the work, and further, if possible, to arrange the quenching plant in such a manner that the work can be withdrawn from the heating chamber, and quenched in the oil or water, as the case may be, without in any way coming in contact with the oxidising influences of the atmosphere. By this method, work can be heated up in the furnace and quenched without in any way affecting the nature of the surface, the work coming from the quenching tank in a bright and metallic condition, without any sign of oxidation, thus surface decarbonisation is entirely eliminated and patchiness of surface hardness reduced to a minimum.

This furnace has proved very satisfactory for the hardening of moulds and special tools used in the production of moulded ware, owing to the ease with which the polished surfaces of the moulds are kept during the hardening operation from being pitted and oxidised, which usually takes place when the work is brought out into the atmosphere to be quenched. It has also proved extremely

useful in connection with the hardening of fine tools, gauges, taps, dies, milling cutters, and, incidentally, been found to produce an improved result with such tools, owing to the fact that the quenching takes place more rapidly, due to the material coming in contact with the quenching medium and not being supported from it by a thin film scale, which in itself constitutes a non-conductive envelope.

As Mr. Creedy has a good deal to say in regard to practical considerations in the hardening shop, I will now conclude my part and ask Mr. Creedy to continue with his part of the paper.

(The Paper by Mr. Creedy and a report of the Discussion will appear in the next issue.)

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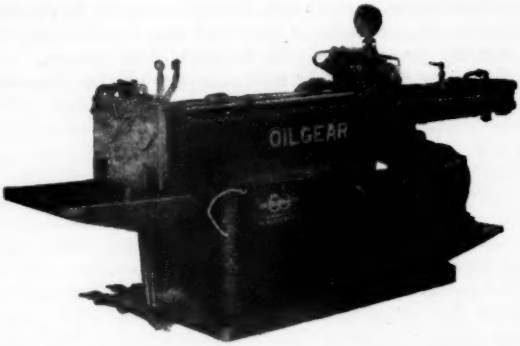

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